VitaRun: Running-Injury Prevention System

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***Abstract*— This report outlines the design proposal for VitaRun. VitaRun seeks to identify different running gait features such us under-pronation, over-pronation and stride length using a machine learning algorithm and provide actionable feedback to the user in order for them to adapt their running style to avoid injury. VitaRun is a complete end-to-end system that collects force and motion data from the user using smart insoles. This data is collected by an Android mobile phone and relayed to to an online data back end. Analysis will be performed and feedback to the user will be communicated using an Android based App.**

I. INTRODUCTION

Running was the most popular sport activity in the UK in 2017. According to the Active Lives Survey, 15% of people surveyed had ran at least twice in the past month [8].The health and fitness benefits of running are well-established. It has been shown to improve mental health [16] and increase life-expectancy; people who run were shown to have a 45% lower risk of cardiovascular associated mortality [15].

While increased running training has great advantages, it is also invariably associated with more injuries [23], [22]. A study showed that for amateurs, across an 8 week training period before a race, at least 1 in 4 (25.9%) participants will have an injury significant enough to restrict running [10]. Risk factors for running-related injuries include lack of experience, previous injuries, running in overused shoes and bio-mechanic risk factors [24], [21]. Some of these are out of the runners control, but the runner can reduce the risk of injuries by controlling their **gait**, where gait is defined as motion achieved through the movement of human limbs [14]. It takes between several weeks to several months to return to running after an injury, hence it is important to focus on early intervention or even prevention of running injuries [14].

Our system aims to address this issue by monitoring selected gait features of the runner through force sensors and an IMU (Inertial Measurement Unit) embedded in an insole, and providing live actionable feedback during the run. It will also provide insights derived from this data and keep a history of runs, allowing the user to observe personal trends.

II. BACKGROUND

A. Bio-mechanic risk factors

Recent research suggests that runners who exhibit relatively large and rapid impact forces while running are at an increased risk of developing an overuse injury of the lower extremity due to a combination of high stress and frequency [14]. Furthermore, deviations from the normal in running mechanics can lead to injuries such as plantar fasciitis, shin splints and a range of knee problems [12].

Fig. 1. Different types of pronation, demonstrated on left foot

Following the advice of a kinesiologist, who researched injury prevention[9], we focus on the following features:

1) Pronation: **Pronation** is a natural movement that occurs during foot landing in walking and running in three planes of human movement and ensures shock absorption. To visualize pronation movement, stand behind a runner and watch how both the heel and the medial side of the ankle roll inward relative to the position of the lower leg [17]. It is well illustrated by Fig. 1 [3]. Due to the interconnection of the bones, joints and ligaments, each movement in pronation influences motion throughout the entire leg up to the hips. Three types are recognised: neutral pronation, under-pronation and over-pronation. In neutral type, the weight distributes fairly evenly among all of the toes with a slight emphasis on the big toe and second toe which are adapted to handle more of the load [11]. In **over-pronation**, push off load is more focused on the big toe and second toe, resulting in poor impact absorption and instability. The muscles of lower extremity compensate, leading to strains and micro-traumas. **Under-pronation** is the opposite and implies the lack of ”inward roll” when the foot impacts the ground. The weight is then transferred to the outside of the foot and the smaller toes, which are not adapted to handle high forces. Despite the wealth of resources available to runners today, studies have shown that they are generally unable to appropriately classify their pronation type [7], [20].

2) Eversion and inversion: **Eversion** and **inversion** describe the frontal plane motion of the ankle, they rarely occur in isolation from abnormal pronation, since they belong to the same chain of movements.Inversion is when the heel faces inwards and the forefoot faces outwards at a high angle. Excessive inversion can lead to sprains. Eversion is the opposite; when the heel faces outwards and the forefoot faces inwards [18].

3) Impact force: Impact force refers to the force that is absorbed by the foot when striking the ground. Higher impact forces have been correlated with injury. Depending upon speed and landing geometry, impact forces vary in magnitude from approximately 1.5 to 5 times the body weight and recede after a very brief period of time (¡30ms) [14]. Studies show that runners who's stride patterns incorporate low levels of impact force and a moderately rapid rate of pronation are at a reduced risk of incurring overuse running injuries [14].

4) Stride length/stride frequency: Reducing stride length leads to reducing impact force, thus preventing injuries, it can be done by increasing step frequency. Recommended frequency is 180 steps per minute, but a sudden change in frequency can lead to injuries. As such we normally suggest decreasing frequency gradually, eventually reaching a 5% to 10% reduction. This will lead to lower force absorption by ankle, knee and hip joints [13].

To achieve gold standard gait analysis an expensive motion capture system is required. However, an adequate level is achievable with a combination of signals from more simple sensors such as accelerometers and gyroscopes placed in an insole. As a result, there is a variety of systems on the market that provide basic gait analysis.

B. Market research

All similar systems currently available on the market focus on running efficiency and coaching, rather than injury prevention. For example, SHFT and Milestone Pod which provide feedback based on metrics such as landing position and brake effect [6], [1] and RunScribe which relies on on-shoe sensors to provide numerous metrics and analysis, but offers no real-time feedback [4].

Similar insole sensors available on the market are Moticon Sensor Insoles, which are marketed to researchers and clinicians, and require expensive software and training [2]. The closest alternative to our system is Retisense, that provides statistics after the run, but no coaching or real-time feedback [5]. The hardware side of this project relies on Retisense's Stridalyzer insoles, as producing a system of high quality, well-calibrated sensors in an insole was beyond its scope.

III. Hypothesis

The null and alternative hypotheses are constructed to test the theory that the mobile health care app is effective in reducing risk of injury to a runner. There are multiple aspects of a runners gait which affect injury, as discussed. Two of these will be tested individually, firstly pronation:

H_0: App feedback results in no change in pronation.

H_1: App feedback results in an improvement in pronation.

This test can be conducted once a sufficiently accurate classification algorithm has been developed. There is only one categorical dependent variable and one categorical independent variable, thus a Pearson Chi-Square Test will be used.

The second test would be for impact force:

H_0: App intervention results in no change in impact force.

H_1: App intervention results in a decrease in impact force.

This test can be conducted earlier in the development process as it does not require an accurate classification algorithm. There is only one categorical dependent variable and one continuous independent variable. Given testing will likely be done on a small number of repeat participants, a Wilcoxon Matched-Pairs Test will be used.

Both tests will be conducted at the 10% significance level.

IV. System Design

A. Discussion of Development Process

The development framework that has been chosen for the project is Android Studio - for deployment onto an Android device. This is because the majority of the team use laptops which run Windows, and therefore cannot be used for iOS development. Frameworks allowing cross platform development were considered, such as Xamarin, Flutter and React Native. However it was deemed that there would be more online support when developing for Android using its native environment. The development process has been divided into 4 sections; UI, hardware, backend, and machine learning. For early stages of development, work can be done on these in parallel, as shown in Fig. 2, since there are elements of them that are functionally independent.

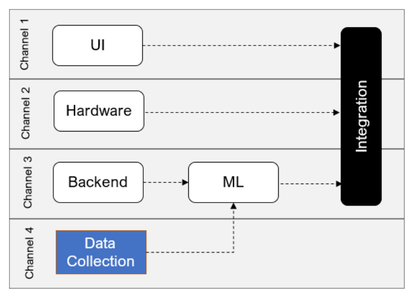

Fig. 2. Diagram Outlining Parallel Development Process

For initial backend and UI development, a mock dataset will be generated in the same format as the data received from the Stridalyzer insoles. This will allow early testing of the data visualization and backend storage methods. Throughout development, a GitHub repository will be used for version control, allowing the team to easily track progress.

B. Hardware

The sensing component of the design will be achieved using a pair of pre-built insoles [5] (Fig. 3) Each insole contains a 6-axis IMU and 10 Piezo resistive force sensors. The insoles use Bluetooth Low Energy (BLE 4.0) to transfer data. The project will also include an Android based smart phone which will collect and send data to the online database, and host the app.

C. Software

For initial troubleshooting with insole communication: BLEMonitor App on Android or LightBlue app on iOS.

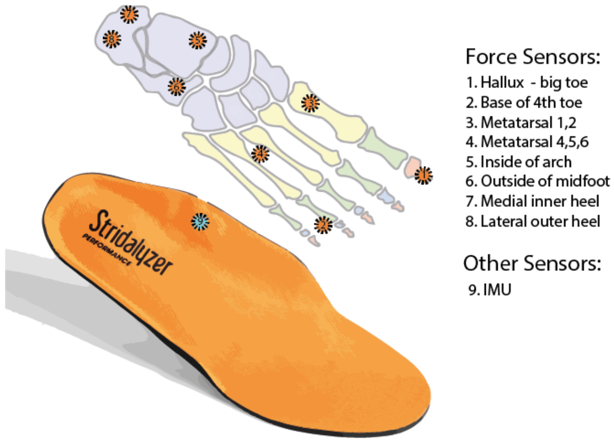

Fig. 3. Stridalyzer Smart Insole (previous model)

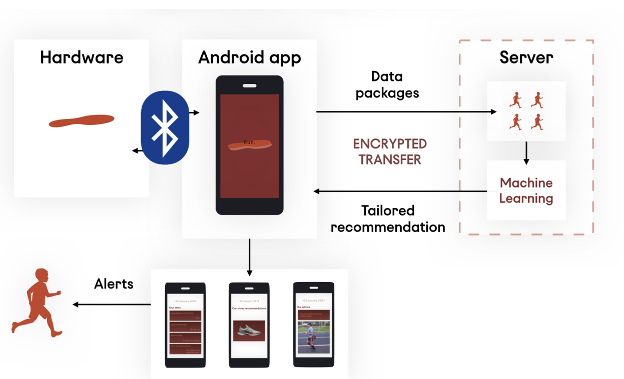

Fig. 4. Proposed System Diagram

1) File Transfer: The insole will connect to the phone via BLE 4.0 protocol. The protocol for this connection has already been designed by the manufacturer and the data transfer protocol has been provided with the insoles. To access the data from the insoles, functions are required to call for specific data, for example GetRunInfo, GetStressInfo and ProccessStride_FRS. This will enable easy access to any required data. A data acquisition protocol will be designed which will in turn call the specific functions to return relevant data from the insoles. This data will then be sent and stored on the server for backend processing. This protocol will start with an initialisation code for the insoles' Bluetooth to connect it to the phone.

The Bluetooth connection to the phone will be fully encrypted using a link key, made during the Bluetooth file sharing protocol. For security, this link key will never be sent over the Bluetooth connection. When the phone accesses the File Transfer Protocol (FTP); the FTP server will require a username and password which will give the app access to only the files under that username. The encryption of the login details for each user will be done using a hashing algorithm. This is a one-way function that will perform a hashing operation such that the password is fully hidden in its respective hashed format. Therefore any breaches to the database will not result in all passwords being leaked. The storage of data on the internet is a very sensitive topic, so the use a modern hashing algorithm seems like the best fit for our app.

2) Front End: The android app is the only interfacing platform between the user VitaRun. The front end of the android app enables the user to start the run, which will initialise the data transfer from the Stridalyzer insoles. In turn, the data packets will be sent to the VitaRun server for them to be encrypted and then stored per profile. During the run, VitaRun will provide the user with feedback on the quality of their stride, either via haptic or audio feedback. At the end of their run, the app will display interactive data visualisations; showing correlations between different aspects of the run. The machine learning algorithm running on the server will then allow the app to give tailored advice on the next run.

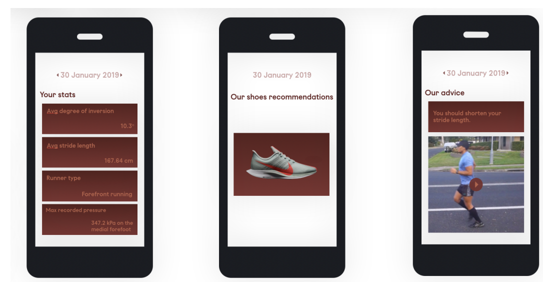

Fig. 5. Screenshots of User Interface

D. Machine Learning

We intend to use machine learning to determine whether the runner is over-pronating. This could be formulated either as a regression problem, where we determine where on the spectrum the runner is, or as a classification problem, where we label the runner as either ”normal”, ”under” or ”excessive” pronation type. Due to the limited time, diversity and quantity of data we can access, and the limitations of labeling without specialised gait analysis, we will treat it as a classification problem. As discusses earlier, excessive eversion or inversion are almost always accompanied by abnormal pronation and require the same correction measures. Hence, our classifier will have the following classes: 1) Under-pronation and eversion, 2) Over-pronation and inversion, 3) Neutral pronation We will perform clustering to confirm that this number of classes is legitimate.

1) Data collection and labeling: Our subjects for training data collection are amateur runners. Our data set aims to represent the diversity of runners, i.e. include runners with different years of experience, different types of pronation and type of strike, with or without previous injuries. Based on studies that used ML to perform classification of gait, signals will be recorded during a 100 second jog, and several sampling frequencies will be tested [19]. To get more diverse data from a runner, we will collect data in the beginning and at the end of the run, when the runner is tired and their control over their gait is wavered, and also ask the runner to run differently e. g by running with correcting shoe inserts.

We will experiment with dividing a recorded labeled run into steps in order to obtain more points for training the classifier.

2) Feature extraction and classification: Sampling time-series data from 10 sensors implies a large volume of multidimensional data, hence we intend to perform PCA (Principal Component Analysis) to reduce dimensionality by extracting features that capture most variance. We will compare performance of different classifiers and use cross-validation to assess the results.

V. Evaluation & Testing

A. Design of Experiment

Upon completion of the prototype, an experiment will be conducted to test the hypothesis that App intervention does result in a more effective stride length. A test set of 5 - 10 runners will be assembled. The runners will be fitted with the device and asked to complete a circuit on two different occasions.

1) Description: The first run will be the control. The runners will wear the device, it will be switched, but not providing feedback. The runners will be told what circuit to run and asked to run it at a pace and gait comfortable to them. The gait data recorded by the device during this run will be stored.

For the second run, the runners will be told how the device works and what it will be doing. The runners will complete the same circuit, aiming for a similar pace. However, this time the device will be providing live, actionable feedback throughout the run. The gait data recorded by the device will be stored, alongside the instances at which feedback was given, and the nature of the feedback.

Following the user testing, the data from the two runs will be compared, considering the time before and after the device gave feedback to the runner. A Wicoxon Matched-Pairs test will be conducted using all 5-10 runner tests to accept or reject the null hypothesis.

2) Variability: The following factors have been identified as risks to the experiment, which could affect the validity of the results:

- Tiredness
- The device causing discomfort during the run
- The user attempting to affect the validity of the results
- Weather and environmental factors affecting gait
- The runner could alter their gait along the run according to expectations of distance and speed

In order to mitigate against these factors, the following steps shall be taken:

- The runs will be completed on different days
- The runs will be completed at the same time of day
- The runner should wear the same shoes for each run
- The runner should have the same target completion time for each run

VI. Conclusion

This report expands on our aim to help amateur runners prevent injuries by correcting their gait. The objectives of this system are to detect abnormal gait patterns and unnecessarily high impact force, and introduce feedback and recommendations based on real-time sensing and machine learning. We hypothesise that these recommendations will help runners improve their gait. We have highlighted why pronation and impact force were chosen as the features to be monitored and outlined implementation plan, system design, evaluation and testing procedures.

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